CONTROL SYSTEM FOR IMPROVED TRANSIENT RESPONSE IN A VARIABLE-GEOMETRY TURBOCHARGER

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/392,923 filed June 28, 2002, which is incorporated by reference herein.

FIELD OF THE INVENTION

This invention relates generally to the field of turbocharger control systems and, more particularly, to a system and method for improving transient response times of a variable-geometry turbocharger.

BACKGROUND OF THE INVENTION

Turbochargers are required to operate over a wide range of engine speeds and loads. Systems have been developed to precisely control the boost provided by the turbocharger by controlling the exhaust gas provided to the turbine of the turbocharger. In general, a control mechanism for controlling the amount of boost provided by a turbocharger includes some type of variable-geometry mechanism that effectively varies the geometry of the turbine inlet nozzle. Such mechanisms can include, for example, multiple movable aerodynamic vanes in the nozzle, or pistons with or without vanes comprising one wall of the nozzle which are axially movable with respect to a fixed nozzle wall. Control of these mechanisms varies depending on application and can include pneumatic, electromechanical, hydraulic, and electro-hydraulic actuation systems. Control of the actuation system can be open-loop or closed-loop or a combination of open- and closed-loop.

The control of a turbocharger is complicated by the inherent lag in the engine exhaust system and the transient response times of the mechanical elements of the variable-geometry mechanism.

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A variable-geometry turbocharger (VGT) such as that disclosed in U.S. Patent No. 6,269,642 uses vanes to guide the airflow in the turbine nozzle and to adjust the flow area of the nozzle to reduce turbo-lag and improve the acceleration of the engine. The VGT employs an electro-hydraulic actuation system that uses an electrical control signal to activate a spool valve that controls the flow of engine oil into and out of an actuator piston cylinder. The actuator force produced for rotating the vanes is proportional to the pressure differential across the actuator piston cylinder. The dynamic response of the vanes is a function of the oil flow and oil pressure and will vary according to the operating conditions such as supply pressure, hydraulic fluid temperature, ambient temperature and valve loading, among other parameters. These effects are sufficient to slow the dynamic response of the turbocharger vanes. Many different methods are used to attain a faster dynamic response. Internal valve parameters (e.g., nozzle and orifice sizes, spring rate, spool diameter, spool displacements, etc.) may be adjusted to produce a faster response. These changes require additional design, testing, and cost for varying application requirements.

Similar control issues arise with wastegates and other variable-geometry devices in turbocharger applications.

It is therefore desirable to have a control system that improves the dynamic response of the variable-geometry mechanism in a turbocharger.

It is also desirable to have a control system that is applicable to existing variable-geometry mechanisms without modification of the existing components.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a schematic diagram of an embodiment of a control system employing the present invention for a closed-loop system;

FIG. 2 is a flow chart for the closed-loop control logic employed by the embodiment of the invention in FIG. 1;

FIG. 3 is a schematic diagram of an embodiment of a control system employing the present invention for an open-loop system;

FIG. 4 is a flow chart for the open-loop control logic employed by the embodiment of the invention in FIG. 3;

FIG. 5 is a diagram of the time varying pulse created by a control system employing the present invention for a positive differential value;

FIG. 6 is a diagram of the time varying pulse created by a control system employing the present invention for a negative differential value;

FIG. 7 is a graphical representation of the amplitude and duration values for the pulses of FIG. 5 and 6 calculated by the control system;

FIG. 8 is a plot of control signal and the resulting actuator displacement produced in a variable-geometry turbocharger as a function of time, for a full range of travel of the actuator, for both a normal control signal as well as a pulsed control signal in accordance with the invention; and

FIG. 9 is a plot of control signal and the resulting actuator displacement produced in a variable-geometry turbocharger as a function of time, for a small range of travel of the actuator, for both a normal control signal as well as a pulsed control signal in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present inventions now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, these inventions may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

The inventive control system includes a supervisor logic that monitors the change in the control signal that is provided for adjusting the variable-geometry mechanism. The supervisor logic selects between a normal control signal output and

a rapid pulse response control signal output to adjust the variable-geometry mechanism. For large changes in the control signal above a predetermined threshold value, the supervisor logic selects the rapid pulse response control output providing a pulse of calculated amplitude and duration to initiate movement of the variable geometry nozzle. The pulse can comprise a virtual step change in the control signal to a value exceeding that of the normal control signal that would ordinarily be applied in the absence of the supervisor logic. The amplitude of the pulse is determined as a function of a difference parameter. The difference parameter can be the difference between a desired (i.e., normal) control signal value and a previous control signal value determined in a previous iteration of the control logic; alternatively, the difference parameter can be the difference between the desired control signal and an actual (measured or estimated) control signal. Whenever the change in the control signal is below the predetermined threshold, the supervisor logic supplies the normal control signal to adjust the variable-geometry mechanism.

The amplitude (or height) and the duration (or width) of the pulse can also be a function of ambient conditions in some embodiments of the invention. This can be advantageous, for example, to account for cold ambient temperature conditions and adjust the response of the valve accordingly.

One embodiment of the present invention is applicable for use on a variable nozzle turbocharger such as that defined in the previously referenced U.S. Patent 6,269,642 entitled VARIABLE GEOMETRY TURBOCHARGER having a common assignee with the present application, the disclosure of which is incorporated by reference herein.

Referring to the drawings, a first embodiment of a control system in accordance with the present invention is shown in FIG. 1. A Rapid Improvement Pulse (RIP) controller **10** incorporates a supervisor logic circuit or arrangement **12** that receives an input **14** from the engine system representing a desired control value. The desired control value is established in various applications as a position of the VGT mechanical system, a desired boost level or an electrical control current. A memory **16** stores the previous desired control value for the previous sample period.

The memory in alternative embodiments incorporates a filtering function for conditioning of the stored control value. The previous control value is provided as a second input **18** to the supervisor logic. The input signals are analyzed, as described in greater detail below, and a switch selection signal **20** is provided to a switch **22** for selection of either a pulse control signal **24** or a normal control signal **26** determined by a VGT position controller **28**. The selected control signal is provided to the actuator **30** for adjusting the variable-nozzle vane position. For the closed-loop control system in the embodiment of FIG. 1, a sensor **32** or model-based estimator detects or estimates an actual operating condition of the turbocharger, such as current, variable-geometry member position, or boost, and provides a feedback signal representing the actual measured or estimated value to a third input **34** of the supervisor logic as well as to a feedback summer **36** for the feedback controller, which computes an error signal **37** that is input to the VGT position controller **28**.

The logic employed in the RIP controller of FIG. 1 is shown in FIG. 2. For each sample period, the supervisor logic **12** reads the desired control value in step **200**. As previously discussed, this value can be a desired variable-geometry member position, desired control current, or a desired boost value depending on the logic and circuitry employed. The supervisor logic in step **202** calculates a first parameter, Delta, as the difference between the new desired control value and the previous desired value (stored in memory **16**). A predetermined threshold value, Gamma (which is a positive number), is compared to Delta in step **204** and if Delta is not greater than +Gamma a determination is made in step **206** whether Delta is less than –Gamma. If either step **204** or step **206** produces an affirmative result, the supervisor logic in step **208** determines a second parameter, Alpha, as the new desired control value minus the actual measured (or estimated) value. In step **210** the supervisor logic tests whether Alpha is greater than +Zeta (a second predetermined threshold); if it is not, then in step **212** the logic tests whether Alpha is less than –Zeta. If either step **210** or step **212** produces an affirmative result, then the supervisor logic determines in step **214** a value for the RIP pulse amplitude and duration (also referred to respectively as the signal height and width). In step **216** the RIP pulse control

signal **24** is provided to the switch **22**, which is positioned to provide the pulse signal to the actuator **30**. At the termination of the pulse, or in any sample period in which the first and second parameters, Delta and Alpha, do not exceed the threshold values Gamma and Zeta, respectively, the switch **22** is positioned to the normal controller input **26**. For example, if step **206** results in a negative result (meaning Delta is not less than –Gamma), the logic returns to step **200**, such that in that sample period the control signal supplied by the switch would be the normal control signal **26**. Similarly, if step **212** results in a negative result (meaning Alpha is not less than –Zeta), then the logic returns to step **200**.

An embodiment of a control system employing the present invention in an open-loop system is shown in FIG. 3. In most open-loop systems, the control input for the turbocharger is defined in terms of a function of engine speed (N) and either percentage of engine load or fuel flow rate as variables in a look-up table or other transfer function generator, represented generally as element **28'**. The elements of the RIP Controller including the supervisor logic **12**, previous control signal memory **16**, and switch **22** operate as previously described in connection with FIG. 1. The logic employed by the open-loop RIP controller is shown in FIG. 4.

For each sample period, the supervisor logic reads the control signal in step **400**. As previously discussed, this value can be a function of engine speed and percent load or fueling rate. The supervisor logic in step **402** calculates a control parameter, Delta, as the difference between the new control signal and the previous control signal. A predetermined threshold value, Gamma, is compared in step **404** and if Delta is not greater than +Gamma a determination is made in step **406** if Delta is less than –Gamma. If either is true, the supervisor logic in step **408** determines a value for the RIP pulse amplitude (or height) and duration (or width). The switch **22** is positioned to the pulse input and the pulse signal is provided to the actuator **30**. At the termination of the pulse, or in any sample period in which the parameter, Delta, does not exceed the threshold value, Gamma, the switch **22** is positioned to the normal control input **26**.

The logic identified in the embodiments shown can be implemented in various computational, hardware or firmware forms with a microprocessor, programmable logic array (PLA), fuzzy logic, neural network, or other discrete logic.

An example of a pulse output provided by the RIP controller is shown in FIG. 5 for a positive pulse resulting from a positive Delta value exceeding the +Gamma threshold. FIG. 6 demonstrates a pulse for a negative Delta value exceeding the –Gamma threshold. The height and width of the pulse in each case are determined in the supervisor logic as a function of the Delta parameter for an open-loop system or the Alpha parameter for a closed-loop system. For example, FIG. 7 shows pulse width and pulse height each as a linear function of either Alpha or Delta (depending on whether the system is closed-loop or open-loop, respectively). Implementation of the pulse generation function in the controller can be effected by a table look-up using tables stored in a memory; alternatively, the pulse generation can be effected by calculating the pulse characteristics based on equations or transfer functions to achieve the desired initiation impulse to the vane control system.

The pulse duration or width can be also determined as a function of the error **37** between the desired and measured or estimated control value as shown in Figure 1.

An RIP controller in accordance with the invention was implemented in a turbocharger system generally similar to that shown in the previously referenced U.S. Patent No. 6,269,642. The control system for the turbocharger employed closed-loop control for controlling the position of variable vanes in the turbine inlet nozzle. FIG. 8 shows the improved response in control vane displacement for a full range displacement (fully closed to fully open) with the use of an RIP controller of the present invention as compared to a normal input control. The pulse generated by the RIP controller is designated with "□" symbols while the normal control signal output is designated with "x" symbols. The resulting vane displacement as a function of time is shown on the curve designated with "◊" symbols for the RIP pulsed input signal; the curve designated with "o" symbols shows the vane displacement achieved using the normal control input signal. The resulting reduction in the transient response time of the vanes is significant.

FIG. 9 is a plot of the same type as FIG. 8, but showing the control signals and transient response of the turbocharger vanes for a small range of vane displacement. It will be noted that there is some overshoot in the response of the displacement. The amount of the overshoot can be controlled by selection of the amplitude and duration of the pulsed control signal. Overshoot can be advantageous in that it can speed the response of the boost pressure, which tends to lag with respect to the vane position. Thus, by intentionally overshooting on vane displacement, the boost pressure can be made to more quickly reach the desired level.

The reduction in transient response time is achieved because the RIP pulsed input signal for a short period of time substantially overshoots the level corresponding to the actual desired position of the variable-geometry vanes. As a result, for that short period of time the actuator is caused to move, essentially at its maximum possible speed, toward the position corresponding to the magnitude of the RIP pulsed signal. In this way, the vanes reach the actual desired position sooner than they would if a normal input signal were supplied to the actuator. In the case of a normal control signal, the actuator is caused to move at less than its maximum possible speed and the speed is substantially constant over the entire period of time that it takes for the vanes to reach the desired position.

The inventive control system is applicable to wastegate control systems and other variable geometry configurations in turbocharger applications.

Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.